operations research
QUANTITATIVE INFRASTRUCTURE SYSTEM MODELING

Long-term Development of European Natural Gas Markets

Scenario Analysis using the Global Gas Model (GGM)

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DIW Berlin

Agenda

Motivation

Putins Invasion of Ukraine

- Unexpected for decades, war within Europe has once again become a reality
  - Invasion of Ukraine on Feb 24th 2022
  - Afterwards, Russian natural gas supplies to Europe (and especially Germany) have become a topic of discussion

Disruption of Supply vs Demand

- Despite a discussion in the German public about an interruption of demand via economic sanctions, supply was disrupted by the Russian side
- Since early September 2022, there have been no more pipeline imports from Russia to Europe via Germany or Poland
- Explosions of the Nord Stream pipelines on September 26th, 2022 have further cemented this state of a “new normal” in European gas markets

Russias Role in European Natural Gas Supply

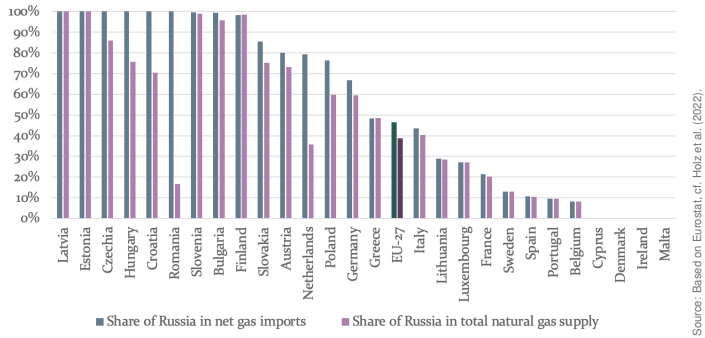
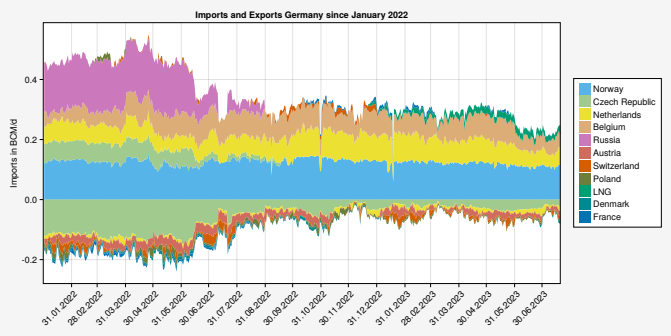


Figure: Russias role in European natural gas supplies.

Historical Overview of German Natural Gas Trade Flows



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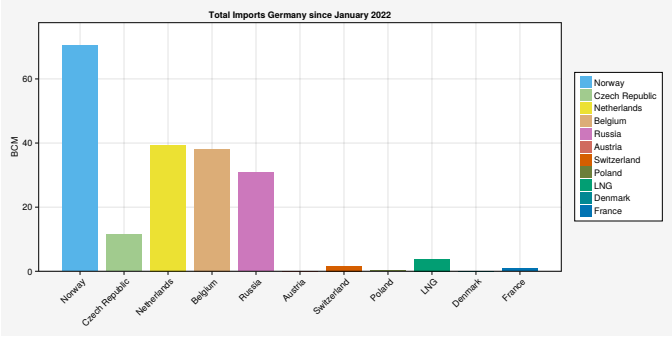

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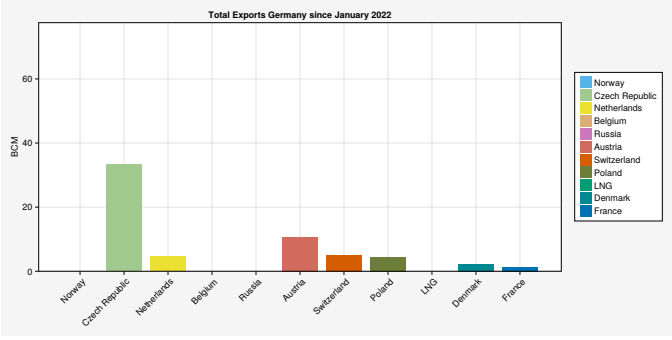

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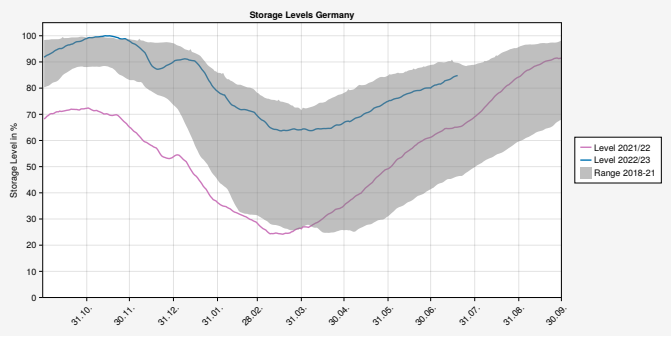

Figure: Historical Natural Gas Trade Flows.

Research Questions

- Short term:
  - High storage levels after Winter 2022/23
  - No serious shortage/outage in gas supplies occured
  - What about the longer term effects of Putins invasion?
- Medium term:
  - Massive extensions of LNG import infrastructure in Germany
  - Following investigations with 32 BCM of exogenous regasification capacity in Germany
    - 22 BCM located by the north sea
    - 10 BCM located in the baltic sea
- Longer Term:
  - Overall Market Developments
  - Risk of Asset Stranding for newly invested regasification capacities?

FSRU Location	Cap (BCMA)	Investment	Operational	Contract (Years)
Wilhelmshaven I	5	Public	2023	10
Brunsbüttel	7.5	Public	2023	10
Stade	5	Public	2024	15
Wilhelmshaven II	4.5	Public	2024	15
Lubmin	10	Private	2023	5-10
FSRU (Total)	32			

Onshore Site	Cap (BCMA)	Investment	Operational
Brunsbüttel	10	Part. Public	2027
Stade	13	Private	2027
Wilhelmshaven	11 (21)	Private	2026
Onshore (Total)	34 (44)		

Table: German LNG Developments.

Agenda

Previous Literature on Russian Supply Disruptions

- Russian supply disruptions have been a possibility discussed and modeled in previous literature
  - With the European Gas Model:
    - Egging et al. (2008)
  - With the World Gas Model:
    - Huppmann et al. (2011)
  - With the Global Gas Model:
    - Richter and Holz (2015)
    - Egging and Holz (2016)
    - Holz et al. (2017)
    - Egging-Bratseth, Holz, and Czempinski (2021)
  - And with other models:
    - Abrell and Weigt (2011)
    - Lochner (2011)
    - Bouwmeester and Oosterhaven (2017)

Agenda

Overview

- Originally a Mixed Complementarity Model
  - Exertion of market power in accordance with a conjectural variation (Nash-Cournot, perfect competition)
- Now a convex QP (Egging-Bratseth, Baltensperger, and Tomasgard 2020)
  - With KKTs equivalent to the MCP
  - Structurally similar to a social welfare optimization
    - Linear inverse demand functions
  - With a market power adjustment term
- Old Data documentation
  - New data
  - New calibration
  - etc.

Objective

$$\max_{q^S_{tndy},\, q^P_{tnrdy},\, f^Z_{tzdy},\, \Delta^Z_{z,y}} \quad \sum_y r_y \left[\right] \tag{1}$$

Objective

$$\max_{q^{S}_{tndy},\, q^{P}_{tnrdy},\, f^{Z}_{tzdy},\, \Delta^{Z}_{z,y}} \quad \sum_{y} r_{y} \left[\sum_{d} d_{d} \left[\right] \right] \tag{1}$$

Objective

$$\max_{\substack{q^{S}_{tndy},\, q^{P}_{tnrdy},\\ f^{Z}_{tzdy},\, \Delta^{Z}_{z,y}}} \quad \sum_{y} r_{y} \left[\sum_{d} d_{d} \left[\sum_{t,n} \left(INT_{ndy} - SLP_{ndy} \sum_{t'} q^{S}_{t'ndy} \right) q^{S}_{tndy} \right] \right] \tag{1}$$

Objective

$$\max_{\substack{q^S_{tndy},\, q^P_{tnrdy},\\ f^Z_{tzdy},\, \Delta^Z_{z,y}}} \quad \sum_y r_y \left[\sum_d d_d \left[\sum_{t,n} \left(INT_{ndy} - SLP_{ndy} \sum_{t'} q^S_{t'ndy} \right) q^S_{tndy} + \frac{1}{2} \sum_n SLP_{ndy} \left(\sum_t q^S_{tndy} \right)^2 \right] \right] \tag{1}$$

Objective

$$\max_{\substack{q^S_{tndy},\, q^P_{tnrdy},\\ f^Z_{tzdy},\, \Delta^Z_{z,y}}} \quad \sum_y r_y \left[\sum_d d_d \left[\sum_{t,n} \left(INT_{ndy} - SLP_{ndy} \sum_{t'} q^S_{t'ndy} \right) q^S_{tndy} + \frac{1}{2} \sum_n SLP_{ndy} \left(\sum_t q^S_{tndy} \right)^2 - \frac{1}{2} \sum_n SLP_{ndy} \sum_t cv_{tny} \left(q^S_{tndy} \right)^2 \right] \right] \tag{1}$$

Objective

$$\max_{\substack{q^{S}_{tndy},\, q^{P}_{tnrdy},\\ f^{Z}_{tzdy},\, \Delta^{Z}_{z,y}}} \quad \sum_{y} r_{y} \left[\sum_{d} d_{d} \left[\sum_{t,n} \left(INT_{ndy} - SLP_{ndy} \sum_{t'} q^{S}_{t'ndy} \right) q^{S}_{tndy} + \frac{1}{2} \sum_{n} SLP_{ndy} \left(\sum_{t} q^{S}_{tndy} \right)^{2} \right. \right.$$
$$\left. \left. - \frac{1}{2} \sum_{n} SLP_{ndy} \sum_{t} cv_{tny} \left(q^{S}_{tndy} \right)^{2} - \sum_{t,n,r} c^{Pl}_{tnry} q^{P}_{tnrdy} - 0.5 \sum_{t,n,r} c^{Pq}_{tnry} \left(q^{P}_{tnrdy} \right)^{2} \right] \right] \tag{1}$$

Objective

$$\max_{\substack{q^S_{tndy},\, q^P_{tnrdy},\\ f^Z_{tzdy},\, \Delta^Z_{z,y}}} \quad \sum_y r_y \left[\sum_d d_d \left[\sum_{t,n} \left(INT_{ndy} - SLP_{ndy} \sum_{t'} q^S_{t'ndy} \right) q^S_{tndy} + \frac{1}{2} \sum_n SLP_{ndy} \left(\sum_t q^S_{tndy} \right)^2 \right. \right.$$
$$\left. - \frac{1}{2} \sum_n SLP_{ndy} \sum_t cv_{tny} \left(q^S_{tndy} \right)^2 - \sum_{t,n,r} c^{Pl}_{tnry} q^P_{tnrdy} - 0.5 \sum_{t,n,r} c^{Pq}_{tnry} \left(q^P_{tnrdy} \right)^2 \right.$$
$$\left. \left. - \sum_{t,a} c^A_{ay} f^A_{tady} - \sum_{t,n,w} c^X_{nwy} f^X_{tnwdy} \right] \right] \tag{1}$$

Objective

$$\max_{\substack{q^S_{tndy},\, q^P_{tnrdy},\\ f^Z_{tzdy},\, \Delta^Z_{z,y}}} \quad \sum_y r_y \left[\sum_d d_d \left[\sum_{t,n} \left(INT_{ndy} - SLP_{ndy} \sum_{t'} q^S_{t'ndy} \right) q^S_{tndy} + \frac{1}{2} \sum_n SLP_{ndy} \left(\sum_t q^S_{tndy} \right)^2 \right. \right.$$
$$- \frac{1}{2} \sum_n SLP_{ndy} \sum_t cv_{tny} \left(q^S_{tndy} \right)^2 - \sum_{t,n,r} c^{Pl}_{tnry} q^P_{tnrdy} - 0.5 \sum_{t,n,r} c^{Pq}_{tnry} \left(q^P_{tnrdy} \right)^2$$
$$\left. - \sum_{t,a} c^A_{ay} f^A_{tady} - \sum_{t,n,w} c^X_{nwy} f^X_{tnwdy} \right]$$
$$\left. - \sum_a c^{\Delta^A_{ay}}_{ay} \Delta^A_{ay} - \sum_x c^{\Delta^X_{xy}}_{xy} \Delta^X_{xy} - \sum_w c^{\Delta^W_{wy}}_{wy} \Delta^W_{wy} \right] \tag{1}$$

Constraints

$$s.t. \quad \forall t, n, r, d, y \qquad q^{P}_{tnrdy} \leq CAP^{P}_{tnry} \tag{2a}$$

(2d)

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$$\forall t, n, d, y \qquad \sum_{r} q^{P}_{tnrdy} + \sum_{a \in A^{+}_{n}} \left(1 - l^{A}_{a}\right) f^{A}_{tady} + \sum_{w(n)} f^{X}_{tnwdy} = q^{S}_{tndy} + \sum_{a \in A^{-}_{n}} f^{A}_{tady} + \sum_{w(n)} f^{I}_{tnwdy} \tag{2b}$$

(2d)

Constraints

$$s.t. \quad \forall t, n, r, d, y \qquad q^{P}_{tnrdy} \leq CAP^{P}_{tnry} \tag{2a}$$

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$$\forall a, y \qquad \Delta^{A}_{ay} \leq \bar{\Delta}^{A}_{ay} \tag{2c}$$

(2d)

Constraints

$$s.t. \quad \forall t, n, r, d, y \qquad q^{P}_{tnrdy} \leq CAP^{P}_{tnry} \tag{2a}$$

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$$\forall a, y \qquad \Delta^{A}_{ay} \leq \bar{\Delta}^{A}_{ay} \tag{2c}$$

$$\forall a, y \qquad \sum_{t} f^{A}_{tady} \leq CAP^{A}_{ay} + \sum_{y' < y} \Delta^{A}_{ay} \tag{2d}$$

Constraints cont'd

$$\forall t, w, y \qquad \left(1 - l_w^I\right) \sum_d d_d f_{twdy}^I = \sum_d d_d f_{twdy}^X \tag{3a}$$

(3e)

Constraints cont'd

$$\forall t, w, y \qquad \left(1 - l^{l}_{w}\right) \sum_{d} d_{d} f^{l}_{twdy} = \sum_{d} d_{d} f^{x}_{twdy} \tag{3a}$$

$$\forall n, w, y \qquad \Delta^{x}_{nwy} \leq \bar{\Delta}^{x}_{nwy} \tag{3b}$$

(3e)

Constraints cont'd

$$\forall t, w, y \qquad \left(1 - l_w^l\right) \sum_d d_d f_{twdy}^l = \sum_d d_d f_{twdy}^x \tag{3a}$$

$$\forall n, w, y \qquad \Delta_{nwy}^x \leq \bar{\Delta}_{nwy}^x \tag{3b}$$

$$\forall n, w, y \qquad \Delta_{nwy}^w \leq \bar{\Delta}_{nwy}^w \tag{3c}$$

(3e)

Constraints cont'd

$$\forall t, w, y \qquad \left(1 - l^{l}_{w}\right) \sum_{d} d_d f^{l}_{twdy} = \sum_{d} d_d f^{X}_{twdy} \tag{3a}$$

$$\forall n, w, y \qquad \Delta^{X}_{nwy} \leq \bar{\Delta}^{X}_{nwy} \tag{3b}$$

$$\forall n, w, y \qquad \Delta^{W}_{nwy} \leq \bar{\Delta}^{W}_{nwy} \tag{3c}$$

$$\forall n, w, d, y \qquad \sum_{t} f^{X}_{tnwdy} \leq CAP^{X}_{nwy} + \sum_{y' < y} \Delta^{X}_{nwy} \tag{3d}$$

(3e)

Constraints cont'd

$$\forall t, w, y \qquad \left(1 - l_w^l\right) \sum_d d_d f_{twdy}^l = \sum_d d_d f_{twdy}^X \tag{3a}$$

$$\forall n, w, y \qquad \Delta_{nwy}^X \leq \bar{\Delta}_{nwy}^X \tag{3b}$$

$$\forall n, w, y \qquad \Delta_{nwy}^W \leq \bar{\Delta}_{nwy}^W \tag{3c}$$

$$\forall n, w, d, y \qquad \sum_t f_{tnwdy}^X \leq CAP_{nwy}^X + \sum_{y'<y} \Delta_{nwy}^X \tag{3d}$$

$$\forall n, w, y \qquad \sum_{t,d} d_d f_{tnwdy}^X \leq CAP_{nwy}^W + \sum_{y'<y} \Delta_{nwy}^W \tag{3e}$$

Agenda

Scenario Overview

STEPS 2021

- Approximately following the World Energy Outlook 2021 "Stated Policies Scenario" (IEA 2021)
  - Where the energy system might go without additional policy implementation
  - Not compatible to the Paris Agreements

STEPS 2022

- Approximately following the World Energy Outlook 2021 "Stated Policies Scenario" (IEA 2022)
  - Where the energy system might go without additional policy implementation
  - Not compatible to the Paris Agreements

APS 2022

- Scenario approximately following the World Energy Outlook 2022 "Announced Pledges Scenario" (IEA 2022)
  - Takes account of climate commitments made
  - Not compatible to the Paris Agreements

NZE 2022

- Scenario approximately following the World Energy Outlook 2022 "Net Zero Emissions" (IEA 2022)
  - Global energy sector should achieve net zero CO_2 emissions by 2050
  - 1.5 ℃ at 50% probability

Scenario Overview

SQAB "Status Quo Ante Bellum"

- Russian exports to Europe and Turkey possible
- Ukraine transit can be used at 100 BCM capacity
- Full capacity on Yamal and Nordstream available
- No limits on Russian exports to turkey

NENO "New Normal"

- Russian exports to Europe partially possible
- Ukraine transit limited to 25 BCM
- No imports via Yamal and Nordstream
- No limits on Russian exports to Turkey

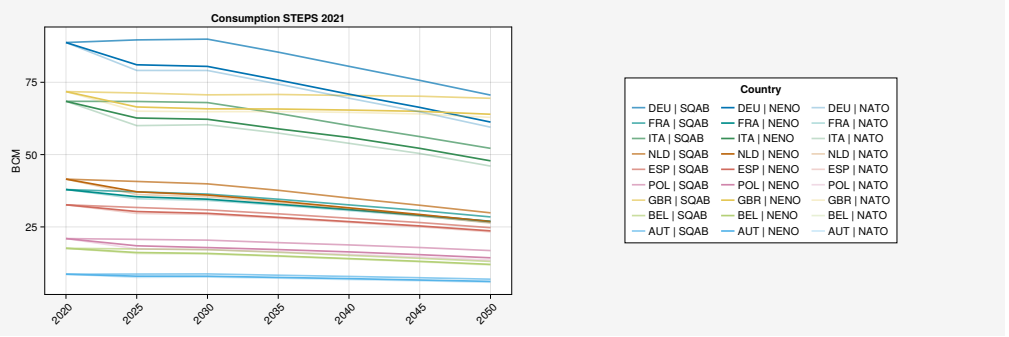
NATO "Extended Supply Disruption"

- No Russian exports to Europe and Turkey
- Ukraine transit limited to 0 BCM
- No imports via Yamal and Nordstream
- Exports via Turkstream etc. disallowed

Note: All demand scenarios are calibrated for the SQAB setting. While this does not precisely capture the spirit of IEA (2022), it unlocks a greater space of observation.

Agenda

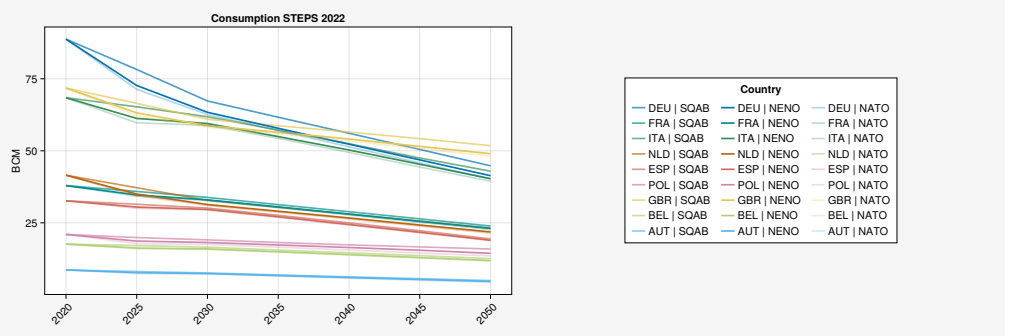
Consumption in STEPS 2021



Source: Own depiction.

Figure: Future natural gas consumption for selected countries.

Consumption in STEPS 2022



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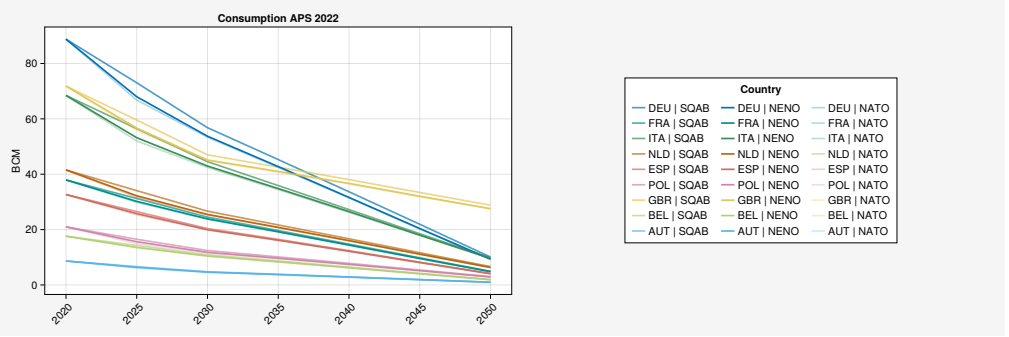
Consumption in APS 2022



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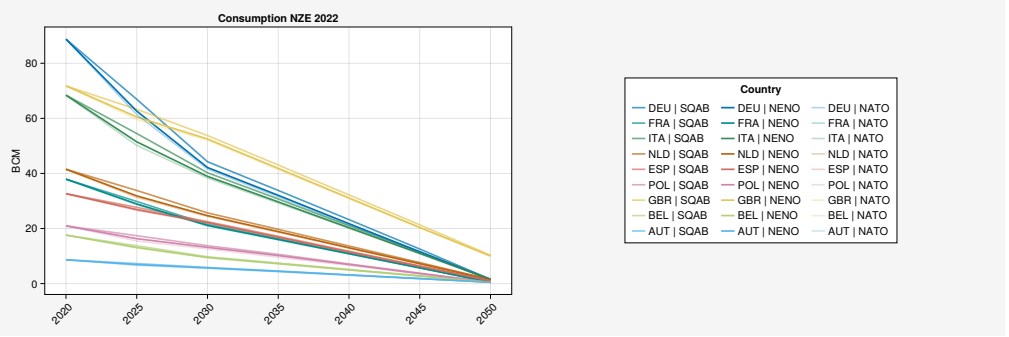
Consumption in NZE 2022



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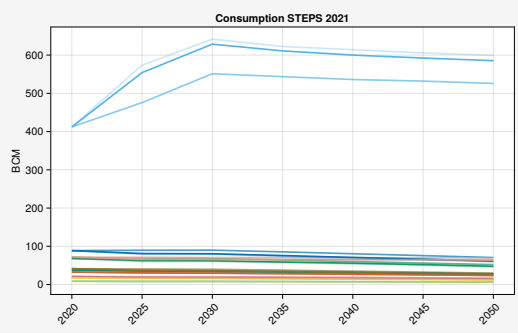

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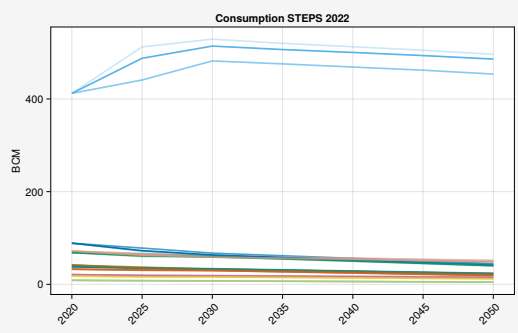
Figure: Future natural gas consumption for selected countries including Russia.

Consumption in STEPS 2022



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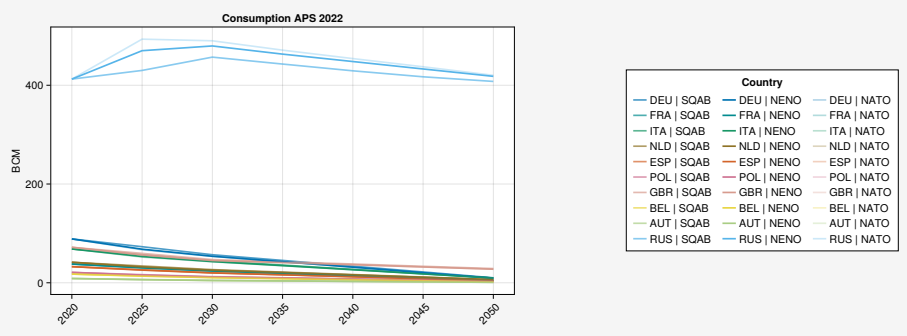
Consumption in APS 2022



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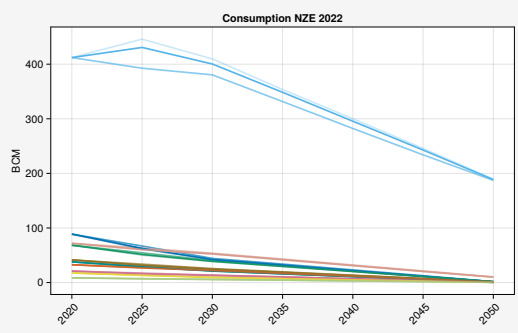

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Utilization of German Regasification Capacities in High Demand Scenarios

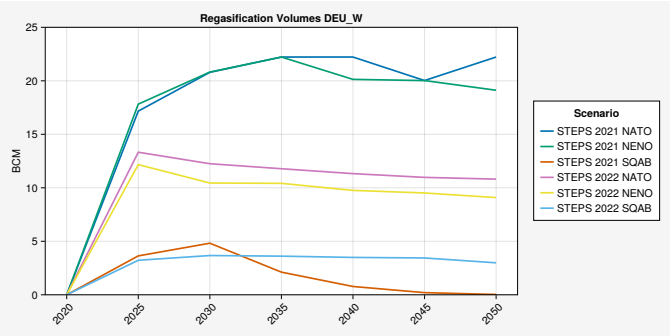

Figure: Utilization of German Regasification Capacities by the North Sea.

Utilization of German Regasification Capacities in High Demand Scenarios

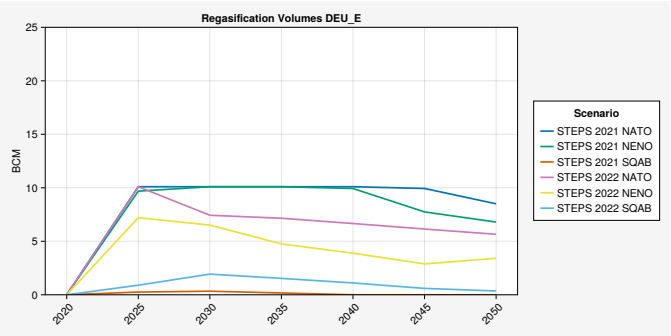

Figure: Utilization of German Regasification Capacities in the Baltic Sea.

Utilization of German Regasification Capacities in Low Demand Scenarios

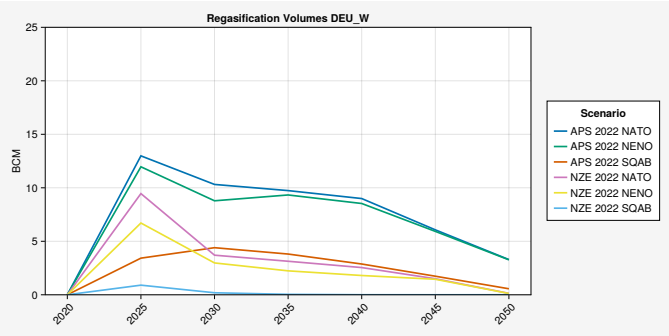

Figure: Utilization of German Regasification Capacities by the North Sea.

Utilization of German Regasification Capacities in Low Demand Scenarios

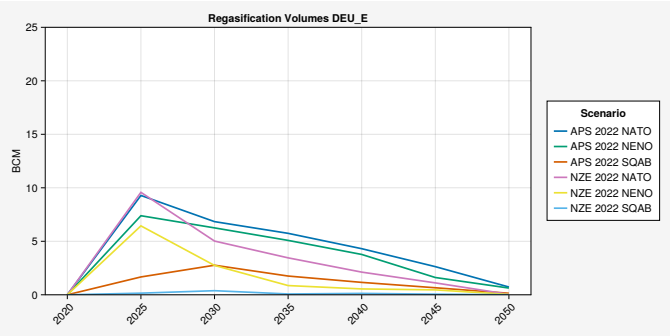

Figure: Utilization of German Regasification Capacities in the Baltic Sea.

Agenda

Conclusions

- There is no incentive to build LNG terminals beyond currently chartered FSRU capacities in Germany
  - Exogenous capacity of ~22/10 BCM suffices,
  - Already invested FSRU capacities are mostly used in high demand, non-paris compatible scenarios
- Decreasing the use of fossil fuels limits effects of supply disruptions
  - Higher prices in turn speed up natural gas exit
  - Underused regasification infrastructure may counter with Lock-In effects
- Russia mostly compensates for disruption by increasing domestic demand
  - Unclear if politial will exists to swamp domestic markets while export revenues decrease
  - Model also does not consider feasibility in domestic grids etc.

Outlook

- Minor refinements in Asia and Africa underway
- Calibration of a fossil free scenario

Agenda

Discussion

Agenda

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Agenda